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PATENT TRADEMARK OFFICE

CHAPTER II

TRANSMITTAL LETTER
TO THE UNITED STATES ELECTED OFFICE (EO/US)

(ENTRY INTO U.S. NATIONAL PHASE UNDER CHAPTER II)

PCT/IL99/00538	13 OCTOBER 1999	9 NOVEMBER 1998
INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED

COMPUTER-IMPLEMENTED METHOD AND SYSTEM FOR DESIGNING TRANSPORTATION ROUTES

TITLE OF INVENTION

DAVID MYR

APPLICANT(S)

Box PCT.
Assistant Commissioner for Patents
Washington D.C. 20231
ATTENTION: EO/US

NOTE: *The completion of those filing requirements that can be made at a time later than 30 months from the priority date results from the Commissioner exercising his judgment under the authority granted under 35 USC 371(d). The filing receipt will show the actual date of receipt of the last item completing the entry into the national phase. See 37 C.F.R.*

CERTIFICATION UNDER 37 C.F.R. 1.10*
*(Express Mail label number is **mandatory**.)*
(Express Mail certification is optional.)

I hereby certify that this correspondence and the documents referred to as attached therein are being deposited with the United States Postal Service on this date May 2, 2001, in an envelope as "Express Mail Post Office to Addressee," Mailing Label Number EL728212684US, addressed to the: Assistant Commissioner for Patents, Washington, D.C. 20231.

BARBARA D. SANTIAGO
(type or print name of person mailing paper)

Barbara D. Santiago
Signature of person mailing paper

WARNING: *Certificate of mailing (first class) or facsimile transmission procedures of 37 C.F.R. 1.8 cannot be used to obtain a date of mailing or transmission for this correspondence.*

****WARNING:*** *Each paper or fee filed by "Express Mail" **must** have the number of the "Express Mail" mailing label placed thereon prior to mailing. 37 C.F.R. 1.10(b).*
*"Since the filing of correspondence under § 1.10 without the Express Mail mailing label thereon is an oversight that can be avoided by the exercise of reasonable care, requests for waiver of this requirement will **not** be granted on petition." Notice of Oct. 24, 1996, 60 Fed. Reg. 56,439, at 56,442.*

§1.491 which states: "An international application enters the national state when the applicant has filed the documents and fees required by 35 USC 371(c) within the periods set forth in § 1.494 and § 1.495."

WARNING: *Where the items are those which can be submitted to complete the entry of the international application into the national phase are subsequent to 30 months from the priority date the application is still considered to be in the international state and if mailing procedures are utilized to obtain a date the express mail procedure of 37 C.F.R. §1.10 must be used (since international application papers are not covered by an ordinary certificate of mailing - See 37 C.F.R. §1.8.*

NOTE: Documents and fees must be clearly identified as a submission to enter the national state under 35 USC 371 otherwise the submission will be considered as being made under 35 USC 111. 37 C.F.R. § 1.494(f).

1. Applicant herewith submits to the United States Elected Office (EO/US) the following items under 35 U.S.C. 371:

   a. [X] This express request to immediately begin national examination procedures (35 U.S.C. 371(f)).

   b. [X] The U.S. National Fee (35 U.S.C. 371(c)(1)) and other fees (37 C.F.R. § 1.492) as indicated below:

2.Fees

CLAIMS FEE	(1) FOR	(2) NUMBER FILED	(3) NUMBER EXTRA	(4) RATE	(5) CALCULA-TIONS
[ ]*	TOTAL CLAIMS	27 - 20 =		x $ 18.00 =	$ 126.00
	INDEPENDENT CLAIMS	2 - 3 =		x $ 80.00 =	
	MULTIPLE DEPENDENT CLAIM(S) (if applicable) + $270.00				
BASIC FEE**	[ ] U.S. PTO WAS INTERNATIONAL PRELIMINARY EXAMINATION AUTHORITY Where an International preliminary examination fee as set forth in § 1.482 has been paid on the international application to the U.S. PTO: [ ] and the international preliminary examination report states that the criteria of novelty, inventive step (non-obviousness) and industrial activity, as defined in PCT Article 33(2) to (4) have been satisfied for all the claims presented in the application entering the national stage (37 CFR 1.492(a)(4)) .... $100.00 [ ] and the above requirements are not met (37 CFR 1.492(a)(1)) .... $690.00 [x] U.S. PTO WAS NOT INTERNATIONAL PRELIMINARY EXAMINATION AUTHORITY Where no international preliminary examination fee as set forth in § 1.482 has been paid to the U.S. PTO, and payment of an international search fee as set forth in § 1.445(a)(2) to the U.S. PTO: [ ] has been paid (37 CFR 1.492(a)(2)) .... $710.00 [ ] has not been paid (37 CFR 1.492(a)(3)) .... $1,000.00 [x] where a search report on the international application has been prepared by the European Patent Office or the Japanese Patent Office (37 CFR 1.492(a)(5)) $860.00				
	Total of above Calculations				$986.00
SMALL ENTITY	Reduction by ½ for filing by small entity, if applicable. Affidavit must be filed. (note 37 CFR 1.9, 1.27, 1.28)				- 493.00
	Subtotal				$493.00
	Total National Fee				$ 493.00
	Fee for recording the enclosed assignment document $40.00 (37 CFR 1.21(h)). (See Item 13 below). See attached "ASSIGNMENT COVER SHEET".				
TOTAL	Total Fees enclosed				$ 493.00

*See attached Preliminary Amendment Reducing the Number of Claims.

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i. [x] A check in the amount of $493.00 ____ to cover the above fees is enclosed.
ii. [ ] Please charge Account No. __________ in the amount of $ __________.
A duplicate copy of this sheet is enclosed.

***WARNING:* *"To avoid abandonment of the application the applicant shall furnish to the United States Patent and Trademark Office not later than the expiration of 30 months from the priority date: * * * (2) the basic national fee (see § 1.492(a)). The 30-month time limit may not be extended." 37 C.F.R. § 1.495(b).*

WARNING: *If the translation of the international application and/or the oath or declaration have not been submitted by the applicant within thirty (30) months from the priority date, such requirements may be met within a time period set by the Office. 37 C.F.R. § 1.495(b)(2). The payment of the surcharge set forth in § 1.492(e) is required as a condition for accepting the oath or declaration later than thirty (30) months after the priority date. The payment of the processing fee set forth in § 1.492(f) is required for acceptance of an English translation later than thirty (30) months after the priority date. Failure to comply with these requirements will result in abandonment of the application. The provisions of § 1.136 apply to the period which is set. Notice of Jan. 3, 1993, 1147 O.G. 29 to 40.*

3. [x] A copy of the International application as filed (35 U.S.C. 371(c)(2)):

NOTE: *Section 1.495 (b) was amended to require that the basic national fee and a copy of the international application must be filed with the Office by 30 months from the priority date to avoid abandonment "The International Bureau normally provides the copy of the international application to the Office in accordance with PCT Article 20. At the same time, the International Bureau notifies applicant of the communication to the Office. In accordance with PCT Rule 47.1, that notice shall be accepted by all designated offices as conclusive evidence that the communication has duly taken place. Thus, if the applicant desires to enter the national stage, the applicant normally need only check to be sure the notice from the International Bureau has been received and then pay the basic national fee by 30 months from the priority date." Notice of Jan. 7, 1993, 1147 O.G. 29 to 40, at 35-36. See item 14c below.*

a. [ ] is transmitted herewith.
b. [ ] is not required, as the application was filed with the United States Receiving Office.
c. [x] has been transmitted
i. [x] by the International Bureau.
Date of mailing of the application (from form PCT/IB/308): __________.
ii. [ ] by applicant on ____________.
Date

4. [x] A translation of the International application into the English language (35 U.S.C. 371(c)(2)):
a. [X] is transmitted herewith.
b. [ ] is not required as the application was filed in English.
c. [ ] was previously transmitted by applicant on ________________.
Date
d. [ ] will follow.

5. [x] Amendments to the claims of the International application under PCT Article 19 (35 U.S.C. 371(c)(3)):

NOTE: The Notice of January 7, 1993 points out that 37 C.F.R. § 1.495(a) was amended to clarify the existing and continuing practice that PCT Article 19 amendments must be submitted by 30 months from the priority date and this deadline may not be extended. The Notice further advises that: "The failure to do so will not result in loss of the subject matter of the PCT Article 19 amendments. Applicant may submit that subject matter in a preliminary amendment filed under section 1.121. In many cases, filing an amendment under section 1.121 is preferable since grammatical or idiomatic errors may be corrected." 1147 O.G. 29-40, at 36.

- a. [ ] are transmitted herewith.
- b. [ ] have been transmitted
  - i. [ ] by the International Bureau.
    Date of mailing of the amendment (from form PCT/IB/308):__________.
  - ii. [ ] by applicant on _____________.
    Date
- c. [x] have not been transmitted as
  - i. [x] applicant chose not to make amendments under PCT Article 19.
    Date of mailing of Search Report (from form PCT/ISA/210):
    28 MARCH 2000.
  - ii. [ ] the time limit for the submission of amendments has not yet expired. The amendments or a statement that amendments have not been made will be transmitted before the expiration of the time limit under PCT Rule 46.1.

6. [x] A translation of the amendments to the claims under PCT Article 19 (38 U.S.C. 371(c)(3)):
- a. [ ] is transmitted herewith.
- b. [ ] is not required as the amendments were made in the English language.
- c. [x] has not been transmitted for reasons indicated at point 5(c) above.

7. [x] A copy of the international examination report (PCT/IPEA/409)
- [x] is transmitted herewith.
- [ ] is not required as the application was filed with the United States Receiving Office.

8. [ ] Annex(es) to the international preliminary examination report
- a. [ ] is/are transmitted herewith.
- b. [ ] is/are not required as the application was filed with the United States Receiving Office.

9. [ ] A translation of the annexes to the international preliminary examination report
- a. [ ] is transmitted herewith.
- b. [ ] is not required as the annexes are in the English language.

10. [x] An oath or declaration of the inventor (35 U.S.C. 371(c)(4)) complying with 35 U.S.C. 115
    a. [ ] was previously submitted by applicant on ____________.
    Date
    b. [ ] is submitted herewith, and such oath or declaration
        i. [ ] is attached to the application.
        ii. [ ] identifies the application and any amendments under PCT Article 19 that were transmitted as stated in points 3(b) or 3(c) and 5(b); and states that they were reviewed by the inventor as required by 37 C.F.R. 1.70.
    c. [x] will follow.

Other document(s) or information included:

11. [x] An International Search Report (PCT/ISA/210) or Declaration under PCT Article 17(2)(a):
    a. [x] is transmitted herewith.
    b. [ ] has been transmitted by the International Bureau.
    Date of mailing (from form PCT/IB/308): ________________.
    c. [ ] is not required, as the application was searched by the United States International Searching Authority.
    d. [ ] will be transmitted promptly upon request.
    e. [ ] has been submitted by applicant on ________________.
    Date

12. [x] An Information Disclosure Statement under 37 C.F.R. 1.97 and 1.98:
    a. [ ] is transmitted herewith.
    Also transmitted herewith is/are:
    [ ] Form PTO-1449 (PTO/SB/08A and 08B).
    [ ] Copies of citations listed.
    b. [x] will be transmitted within THREE MONTHS of the date of submission of requirements under 35 U.S.C. 371(c).
    c. [ ] was previously submitted by applicant on ________________.
    Date

13. [ ] An assignment document is transmitted herewith for recording.

A separate [ ] "COVER SHEET FOR ASSIGNMENT (DOCUMENT) ACCOMPANYING NEW PATENT APPLICATION" or [ ] FORM PTO 1595 is also attached.

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14. [x] Additional documents:

a. [ ] Copy of request (PCT/RO/101)

b. [x] International Publication No. WO 00/28448

i. [x] Specification, claims and drawing

ii. [ ] Front page only

c. [ ] Preliminary amendment (37 C.F.R. § 1.121)

d. [x] Other

5 PAGES OF DRAWINGSFORM PCT/ISA/220; FORM PCT/IPEA/408; FORM PCT/IPEA/409 FORM PCT/IPEA/416; RESPONSE TO WRITTEN OPINION

15. [x] The above checked items are being transmitted

a. [x] before 30 months from any claimed priority date.

b. [ ] after 30 months.

16. [ ] Certain requirements under 35 U.S.C. 371 were previously submitted by the applicant on ____________, namely:

AUTHORIZATION TO CHARGE ADDITIONAL FEES

WARNING: *Accurately count claims, especially multiple dependent claims, to avoid unexpected high charges if extra claims are authorized.*

NOTE: *"A written request may be submitted in an application that is an authorization to treat any concurrent or future reply, requiring a petition for an extension of time under this paragraph for its timely submission, as incorporating a petition for extension of time for the appropriate length of time. An authorization to charge all required fees, fees under § 1.17, or all required extension of time fees will be treated as a constructive petition for an extension of time in any concurrent or future reply requiring a petition for an extension of time under this paragraph for its timely submission. Submission of the fee set forth in § 1.17(a) will also be treated as a constructive petition for an extension of time in any concurrent reply requiring a petition for an extension of time under this paragraph for its timely submission." 37 C.F.R. § 1.136(a)(3).*

NOTE: *"Amounts of twenty-five dollars or less will not be returned unless specifically requested within a reasonable time, nor will the payer be notified of such amounts; amounts over twenty-five dollars may be returned by check or, if requested, by credit to a deposit account." 37 C.F.R. § 1.26(a).*

[X] The Commissioner is hereby authorized to charge the following additional fees that may be required by this paper and during the entire pendency of this application to Account No. 12-0425.

[X] 37 C.F.R. 1.492(a)(1), (2), (3), and (4) (filing fees)

WARNING: *Because failure to pay the national fee within 30 months without extension (37 C.F.R. § 1.495(b)(2)) results in abandonment of the application, it would be best to always check the above box.*

[ ] 37 C.F.R. 1.492(b), (c) and (d) (presentation of extra claims)

NOTE: *Because additional fees for excess or multiple dependent claims not paid on filing or on later presentation must*

only be paid or these claims cancelled by amendment prior to the expiration of the time period set for response by the PTO in any notice of fee deficiency (37 C.F.R. § 1.492(d)), it might be best not to authorize the PTO to charge additional claim fees, except possible when dealing with amendments after final action.

[X] 37 C.F.R. 1.17 (application processing fees)
[X] 37 C.F.R. 1.17(a)(1)-(5)(extension fees pursuant to § 1.136(a).
[X] 37 C.F.R. 1.18 (issue fee at or before mailing of Notice of Allowance, pursuant to 37 C.F.R. 1.311(b))

NOTE: Where an authorization to charge the issue fee to a deposit account has been filed before the mailing of a Notice of Allowance, the issue fee will be automatically charged to the deposit account at the time of mailing the notice of allowance. 37 C.F.R. § 1.311(b).

NOTE: 37 C.F.R. 1.28(b) requires "Notification of any change in loss of entitlement to small entity status must be filed in the application . . . prior to paying, or at the time of paying . . . issue fee." From the wording of 37 C.F.R. § 1.28(b): (a) notification of change of status must be made even if the fee is paid as "other than a small entity" and (b) no notification is required if the change is to another small entity.

[ ] 37 C.F.R. § 1.492(e) and (f) (surcharge fees for filing the declaration and/or filing an English translation of an International Application later than 30 months after the priority date).

SIGNATURE OF PRACTITIONER

Reg. No.: 25, 858

WILLIAM R. EVANS
(type or print name of practitioner)

Tel. No.: (212) 708-1930

P.O. Address

Customer No.: 00140

c/o Ladas & Parry
26 West 61st Street
New York, N.Y. 10023

JC17 Rec'd PCT/PTO 19 JUN 2001

5010

PCT #3

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of: DAVID MYR
Serial No.: 09/831,093
Filed: MAY 3, 2001
For: COMPUTER-IMPLEMENTED METHOD AND SYSTEM FOR DESIGNING TRANSPORTATION ROUTES

Group No.:

Examiner:

Attorney Docket No.:U013436-2
Assistant Commissioner for Patents
Washington, D.C. 20231

PRELIMINARY AMENDMENT

3. (Amended) The method according to Claim 1, wherein the route profile data includes soil composition and per unit excavation cost for each different level having a discrete soil composition.

4. (Amended) The method according to Claim 1, wherein: the height profile is computed to minimize a total cost of the earthworks represented by the following objective function:

CERTIFICATE OF MAILING (37 CFR 1.8a)

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being deposited with the United States Postal Service on the date shown below with sufficient postage as first class mail in an envelope addressed to the: Assistant Commissioner of Patents and Trademarks, Washington, D.C. 20231

William R. Evans
(Type or print name of person mailing paper)

Date: June 14, 2001

(Signature of person mailing paper)

$$\sum_{q=1}^{q=N}(F_q(Z_q)\cdot G+W_q(Z_q)+C_q(Z_q)\cdot G+V_q(Z_q))\cdot G+D$$

where:

G	is grid size;
$F_q(Z_q)$	is cost of fill at point Q, where the proposed GP elevation is higher than the existing GP elevation ($Z_q>0$);
$W_q(Z_q)$	is cost of retaining wall for fill at point Q, where proposal GP is above existing GP ($Zq>0$);
$C_q(Z_q)$	is cost of excavation at point Q, where the proposed GP is lower than the existing GP ($Z_q<0$);
$V_q(Z_q)$	is cost of retaining wall for excavation at point Q, where proposed GP is below existing GP ($Z_q<0$);
D	is cost of total difference between fill and excavation volumes moving in or out of entire roads system area.

$Z_q = Z'_q - Z_e$, where Z'_q is the proposed elevation and Z_e is the elevation at point Q,

the cost $C_q(Z_q)$ is represented as the solution of a non-linear equation represented by:

$$C_q(Z_q)=0.5\cdot\left(\sum_{j=1}^{j=Kq}\left(\left|Z_q-aj_q\right|+aj_q-\left|Z_q-bj_q\right|-bj_q\right)\ Pj_q+\left\{\left|Z_q-bK_q\right|-\left(Z_q-bK_q\right)\right\}\cdot P_q\max\right)$$

and

each of the absolute expressions $Z_q - a_i$, $Z_q - b_i$, $Z_q - c_j$, $Z_q - d_j$, $Z_q - e_j$, $Z_q - f_j$ is replaced by a pair of new variables, as follows:

(*) Z_q - ai = $Uqai_1 - Uqai_2$, i=1,...,Kq,

(*) Z_q - bi = $Uqbi_1 - Uqbi_2$, i=1,...,Kq,

(*) Z_q - bKq = $UqbK_1 - UqbK_2$;

(*) $Z_q - c_j = Uqcj_1 - Uqcj_2$, j=1,...,L,

(*) $Z_q - d_j = Uqdj_1 - Uqdj_2$, j=1,...,L,

(*) $Z_q - d_L = UqdL_1 - UqdL_2$;

(*) $Z_q - e_j = Uqej_1 - Uqej_2$, j=1,...,M,

(*) $Z_q - f_j = Uqfj_1 - Uqfj_2$, j=1,...,M,

(*) $Z_q - f_M = UqfM_1 - UqfM_2$.

so as to render all of the constraints linear and amenable to computation using Linear Programming techniques.

5. (Amended) The method according to Claim 2, further including:
(e) iteratively shifting said model vertically in order to minimize total cost whilst taking into account the cross-section of each transportation route, so as to derive a set of control points having elevations that define vertical alignment of the transportation routes.

7. (Amended) The method according to Claim 5, wherein accuracy is improved by reducing a mutual separation between adjacent grid points.

8. (Amended) The method according to Claim 5, wherein accuracy is improved by providing a higher resolution digital terrain model.

9. (Amended) The method according to Claim 2, wherein at least one of the transportation routes includes one or more subdivision lots adjoining a boundary of the

transportation route and in step (d)(i) there are added to the model respective sections and boundaries of said subdivision lots so as to take into account earthworks required to conform an elevation of the transportation route to corresponding elevations of the subdivision lots.

10. (Amended) The method according to Claim 1, wherein the transportation routes include at least one road.

11. (Amended) The method according to Claim 1, wherein the transportation routes include at least one rail track.

12. (Amended) The method according to Claim 1, wherein the transportation routes include at least one pedestrian path.

13. (Amended) The method according to Claim 1 applied to a plurality of transportation routes comprising an integrated project so as optimize excavation costs for the project.

16. (Amended) The system according to Claim 15, wherein the route profile data includes soil composition and per unit excavation cost for each different level having a discrete soil composition.

17. (Amended) The system according to Claim 14, wherein wherein the computer is programmed to compute the height profile by minimizing a total cost of the earthworks represented by the following objective function:

$$\sum_{q=1}^{q=N}(F_q(Z_q)\cdot G+W_q(Z_q)+C_q(Z_q)\cdot G+V_q(Z_q))\cdot G+D$$

where:

G	is grid size;
$F_q(Z_q)$	is cost of fill at point Q, where the proposed GP elevation is higher than the existing GP elevation ($Z_q>0$);
$W_q(Z_q)$	is cost of retaining wall for fill at point Q, where proposal GP is above existing GP ($Zq>0$);
$C_q(Z_q)$	is cost of excavation at point Q, where the proposed GP is lower than the existing GP ($Z_q<0$);
$V_q(Z_q)$	is cost of retaining wall for excavation at point Q, where proposed GP is below existing GP ($Z_q<0$);
D	is cost of total difference between fill and excavation volumes moving in or out of entire roads system area.

$Z_q = Z'_q - Z_e$, where Z'_q is the proposed elevation and Z_e is the elevation at point Q,

the cost $C_q(Z_q)$ is represented as the solution of a non-linear equation represented by:

$$C_q(Z_q)=0.5\cdot\left(\sum_{j=1}^{j=Kq}\left(\left|Z_q-aj_q\right|+aj_q-\left|Z_q-bj_q\right|-bj_q\right)\cdot Pj_q+\left\{\left|Z_q-bK_q\right|-\left(Z_q-bK_q\right)\right\}\cdot P_q\max\right)$$

and

each of the absolute expressions $Z_q - a_i$, $Z_q - b_i$, $Z_q - c_j$, $Z_q - d_j$, $Z_q - e_j$, $Z_q - f_j$ is replaced by a pair of new variables, as follows:

(*) Z_q - ai = $Uqai_1 - Uqai_2$, i=1,...,Kq,

(*) Z_q - bi = $Uqbi_1 - Uqbi_2$, i=1,...,Kq,

(*) Z_q - bKq = $UqbK_1 - UqbK_2$;

(*) Z_q - c_j = $Uqcj_1 - Uqcj_2$, j=1,...,L,

(*) Z_q - d_j = $Uqdj_1 - Uqdj_2$, j=1,...,L,

(*) Z_q - d_L = $UqdL_1 - UqdL_2$;

(*) Z_q - e_j = $Uqej_1 - Uqej_2$, j=1,...,M,

(*) Z_q - f_j = $Uqfj_1 - Uqfj_2$, j=1,...,M,

(*) Z_q - f_M = $UqfM_1 - UqfM_2$.

so as to render all of the constraints linear and amenable to computation using Linear Programming techniques.

18. (Amended) The system according to Claim 15, further including: (f) a vertical shifter for iteratively shifting said model vertically in order to minimize total cost whilst taking into account the cross-section of each transportation route, so as to derive a set of control points having elevations that define vertical alignment of the transportation routes.

20. (Amended) The system according to Claim 18, wherein accuracy is improved by reducing a mutual separation between adjacent grid points.

21. (Amended) The system according to Claim 18, wherein accuracy is improved by providing a higher resolution digital terrain model.

22. (Amended) The system according to Claim 15, wherein: at least one of the transportation routes includes one or more subdivision lots adjoining a boundary of the

transportation route, there is further stored in the memory data relating to respective sections and boundaries of said subdivision lots, and the computer is responsive to the respective sections and boundaries of the subdivision lots so as to take into account earthworks required to conform an elevation of the transportation route to corresponding elevations of the subdivision lots.

23. (Amended) The system according to Claim 14, wherein the transportation route data includes data relating to at least one road.

24. (Amended) The system according to Claim 1, wherein the transportation route data includes data relating to at least one rail track.

25. (Amended) The system according to Claim 14, wherein the transportation route data includes data relating to at least one pedestrian path.

26. (Amended) The system according to Claim 14 for processing data relating a plurality of transportation routes comprising an integrated project so as optimize excavation costs for the project.

27. (Amended) A storage medium storing therein a computer program for carrying out the method of Claim 1.

REMARKS

The above amendatory action is taken for the purpose to avoid claim fees that would otherwise accrue due to the presence of multiply dependent claims.

Respectfully submitted,

WILLIAM R. EVANS
LADAS & PARRY
26 WEST 61ST STREET
NEW YORK, NEW YORK 10023
REG.NO. 25,858 (212)708- 1930

MARK-UP

3. (Amended) The method according to Claim 1 [or 2], wherein the route profile data includes soil composition and per unit excavation cost for each different level having a discrete soil composition.

4. (Amended) The method according to <u>Claim 1</u> [any one of the preceding claims], wherein: the height profile is computed to minimize a total cost of the earthworks represented by the following objective function:

$$\sum_{q=1}^{q=N}(F_q(Z_q)\cdot G+W_q(Z_q)+C_q(Z_q)\cdot G+V_q(Z_q))\cdot G+D$$

where:

G	is grid size;
$F_q(Z_q)$	is cost of fill at point Q, where the proposed GP elevation is higher than the existing GP elevation ($Z_q>0$);
$W_q(Z_q)$	is cost of retaining wall for fill at point Q, where proposal GP is above existing GP (Zq>0);
$C_q(Z_q)$	is cost of excavation at point Q, where the proposed GP is lower than the existing GP ($Z_q<0$);
$V_q(Z_q)$	is cost of retaining wall for excavation at point Q, where proposed GP is below existing GP ($Z_q<0$);
D	is cost of total difference between fill and excavation volumes moving in or out of entire roads system area.

$Z_q = Z'_q - Z_e$, where Z'_q is the proposed elevation and Z_e is the elevation at point Q,

the cost $C_q(Z_q)$ is represented as the solution of a non-linear equation represented by:

$$C_q(Z_q)=0.5\cdot\left(\sum_{j=1}^{j=Kq}\left(\left|Z_q-aj_q\right|+aj_q-\left|Z_q-bj_q\right|-bj_q\right)\cdot Pj_q+\left\{\left|Z_q-bK_q\right|-\left(Z_q-bK_q\right)\right\}\cdot P_q\max\right.$$

and

each of the absolute expressions $Z_q - a_i$, $Z_q - b_i$, $Z_q - c_j$, $Z_q - d_j$, $Z_q - e_j$, $Z_q - f_j$ is replaced by a pair of new variables, as follows:

(*) Z_q - ai = Uqai$_1$ – Uqai$_2$, i=1,…,Kq,

(*) Z_q - bi = Uqbi$_1$ – Uqbi$_2$, i=1,…,Kq,

(*) Z_q - bKq = UqbK$_1$ – UqbK$_2$;

(*) Z_q - c_j = Uqcj$_1$ – Uqcj$_2$, j=1,…,L,

(*) Z_q - d_j = Uqdj$_1$ – Uqdj$_2$, j=1,…,L,

(*) Z_q - d_L = UqdL$_1$ – UqdL$_2$;

(*) Z_q - e_j = Uqej$_1$ – Uqej$_2$, j=1,…,M,

(*) Z_q - f_j = Uqfj$_1$ – Uqfj$_2$, j=1,…,M,

(*) Z_q - f_M = UqfM$_1$ – UqfM$_2$.

so as to render all of the constraints linear and amenable to computation using Linear Programming techniques.

5. (Amended) The method according to Claim 2 [or 3], further including: (e) iteratively shifting said model vertically in order to minimize total cost whilst taking into account the cross-section of each transportation route, so as to derive a set of control points having elevations that define vertical alignment of the transportation routes.

7. (Amended) The method according to Claim 5 [or 6], wherein accuracy is improved by reducing a mutual separation between adjacent grid points.

8. (Amended) The method according to [any one of Claims] <u>Claim</u> 5 [to 7], wherein accuracy is improved by providing a higher resolution digital terrain model.

9. (Amended) The method according to [any one of the Claims] <u>Claim</u> 2 [to 8], wherein at least one of the transportation routes includes one or more subdivision lots adjoining a boundary of the transportation route and in step (d)(i) there are added to the model

respective sections and boundaries of said subdivision lots so as to take into account earthworks required to conform an elevation of the transportation route to corresponding elevations of the subdivision lots.

10. (Amended) The method according to [any one of the preceding claims] Claim 1, wherein the transportation routes include at least one road.

11. (Amended) The method according to [any one of the preceding claims] Claim 1, wherein the transportation routes include at least one rail track.

12. (Amended) The method according to [any one of the preceding claims] Claim 1, wherein the transportation routes include at least one pedestrian path.

13. (Amended) The method according to [any one of the preceding claims] Claim 1 applied to a plurality of transportation routes comprising an integrated project so as optimize excavation costs for the project.

16. (Amended) The system according to [any one of Claims] Claim 15, wherein the route profile data includes soil composition and per unit excavation cost for each different level having a discrete soil composition.

17. (Amended) The system according to [any one of Claims] Claim 14 [to 16], wherein wherein the computer is programmed to compute the height profile by minimizing a total cost of the earthworks represented by the following objective function:

$$\sum_{q=1}^{q=N}(F_q(Z_q)\cdot G + W_q(Z_q) + C_q(Z_q)\cdot G + V_q(Z_q))\cdot G + D$$

where:

G is grid size;

$F_q(Z_q)$ is cost of fill at point Q, where the proposed GP elevation is higher than the existing GP elevation ($Z_q>0$);

$W_q(Z_q)$ is cost of retaining wall for fill at point Q, where proposal GP is above existing GP (Zq>0);

$C_q(Z_q)$ is cost of excavation at point Q, where the proposed GP is lower than the existing GP (Z_q<0);

$V_q(Z_q)$ is cost of retaining wall for excavation at point Q, where proposed GP is below existing GP (Z_q<0);

D is cost of total difference between fill and excavation volumes moving in or out of entire roads system area.

$Z_q = Z'_q - Z_e$, where Z'_q is the proposed elevation and Z_e is the elevation at point Q,

the cost $C_q(Z_q)$ is represented as the solution of a non-linear equation represented by:

$$C_q(Z_q) = 0.5 \cdot \left(\sum_{j=1}^{j=Kq} \left(\left| Z_q - aj_q \right| + aj_q - \left| Z_q - bj_q \right| - bj_q \right) \cdot Pj_q + \left\{ \left| Z_q - bK_q \right| - \left(Z_q - bK_q \right) \right\} \cdot P_q \max \right)$$

and

each of the absolute expressions $Z_q - a_i$, $Z_q - b_i$, $Z_q - c_j$, $Z_q - d_j$, $Z_q - e_j$, $Z_q - f_j$ is replaced by a pair of new variables, as follows:

(*) Z_q - ai = $Uqai_1 - Uqai_2$, i=1,...,Kq,

(*) Z_q - bi = $Uqbi_1 - Uqbi_2$, i=1,...,Kq,

(*) Z_q - bKq = $UqbK_1 - UqbK_2$;

(*) Z_q - c_j = $Uqcj_1 - Uqcj_2$, j=1,...,L,

(*) Z_q - d_j = $Uqdj_1 - Uqdj_2$, j=1,...,L,

(*) Z_q - d_L = $UqdL_1 - UqdL_2$;

(*) Z_q - e_j = $Uqej_1 - Uqej_2$, j=1,...,M,

(*) Z_q - f_j = $Uqfj_1 - Uqfj_2$, j=1,...,M,

(*) Z_q - f_M = $UqfM_1 - UqfM_2$.

so as to render all of the constraints linear and amenable to computation using Linear Programming techniques.

18. (Amended) The system according to Claim 15 [to 17], further including: (f) a vertical shifter for iteratively shifting said model vertically in order to minimize total cost whilst taking into account the cross-section of each transportation route, so as to derive a set of control points having elevations that define vertical alignment of the transportation routes.

20. (Amended) The system according to Claim 18 [or 19], wherein accuracy is improved by reducing a mutual separation between adjacent grid points.

21. (Amended) The system according to [any one of Claims] Claim 18 [to 20], wherein accuracy is improved by providing a higher resolution digital terrain model.

22. (Amended) The system according to [any one of the Claims] Claim 15 [to 21], wherein: at least one of the transportation routes includes one or more subdivision lots adjoining a boundary of the transportation route, there is further stored in the memory data relating to respective sections and boundaries of said subdivision lots, and the computer is responsive to the respective sections and boundaries of the subdivision lots so as to take into account earthworks required to conform an elevation of the transportation route to corresponding elevations of the subdivision lots.

23. (Amended) The system according to [any one of Claims] Claim 14 [to 22], wherein the transportation route data includes data relating to at least one road.

24. (Amended) The system according to [any one of the preceding claims] Claim 1, wherein the transportation route data includes data relating to at least one rail track.

25. (Amended) The system according to [any one of Claims] Claim 14 [to 24], wherein the transportation route data includes data relating to at least one pedestrian path.

26. (Amended) The system according to [any one of Claims] Claim 14 [to 25] for processing data relating a plurality of transportation routes comprising an integrated project so as optimize excavation costs for the project.

27. (Amended) A storage medium storing therein a computer program for carrying out the method of [any one of claims] Claim 1 [to 13].

Computer-implemented method and system for designing transportation routes

FIELD OF THE INVENTION

This invention relates to techniques for designing transport routes.

BACKGROUND OF THE INVENTION

Conventional approaches to the road design rely on separate design for each road system. Thus, the design of road systems usually begins with the planning stage where a civil engineer arranges the road to satisfy the standard specifications such as grade and meeting of centerlines at intersections. Then a draftsman produces an initial design using one of numerous software programs to draft profiles, vertical alignment, measure cross-sections and calculate the cut and fill quantities. In this connection, it will be appreciated that road surfaces are generally not level. Whenever a gradient is associated with the road surface, this requires that, during construction, earth be removed ("cut") from those sections which are lower than the foundation level and that earth be added to those sections which are higher than the foundation level and must therefore be "filled". Such earthworks require skilled operation of heavy and expensive machinery and is therefore highly costly. It is therefore desirable, as far as is possible, to equalize the cut and fill quantities so as to avoid unnecessary earthworks.

Such equalization is an iterative process requiring repeated fine–tuning by the engineer. The iteration may be repeated numerous times before the road system satisfies all of the physical constraints and the cut and fill quantities are properly balanced. Conventionally, the design has been a trial and error affair according to the experience of the civil engineer. The vertical alignment is determined for one road at a time and not for the entire road system. Earthworks of subdivision lots which border transportation routes have also not conventionally been taken into account, nor has the economical factor been properly considered.

A CAD approach to the design of rail tracks is presented by L.G. Allen *et al.* in "*Cost Effective Design – The Use of Computer Aided Drafting In: Route Selection, Earthworks Optimisation and Rail Track Engineering*" appearing in Conference on Railway Engineering, Perth/Australia, September 1987; XP-000917757. However, this article makes no reference to minimization of earthworks cost. Rather it attempts to achieve cost-effective design using an interactive CAD process. Thus, cost effectiveness is the result of user's interactive work (i.e. trial and error) and is not an automatic computerized process that uses pre-prepared data allowing the route to be optimized without any user interaction. In this respect, the CAD tools disclosed by this article are typical of prior art methods that relate on trial and error for optimizing transportation routes.

SUMMARY OF THE INVENTION

A principal the object of the invention is thus to develop a method of road design that results in lower construction cost.

A further object of the invention is to facilitate comparison of different layouts and different unit prices so as to obtain better cost-effectiveness during the preliminary planning stage.

According to a broad aspect of the invention there is provided a computer-implemented method for designing transportation routes, the method comprising the steps of:

(a) supplying linear constraints of allowable grades to be met in respect of at least one of said transportation routes,

(b) obtaining route profile 3-D coordinates showing land heights at sampled points along each of said at least one transportation route prior to construction thereof,

(c) supplying cost estimates per working unit in respect of land-cut and land-fill operations, and

(d) computing a height profile of said at least one transportation route which meets said constraints and for which said land-cut and land-fill operations are adjusted to give a minimum cost by replacing all non-linear constraints by equivalent linear constraints so as to render the height profile solving using standard linear programming tools.

Such a method establishes a direct relationship between prevailing economic conditions and the status of the transportation system as a technical

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entity. The method according to the invention utilizes customized optimization which operate on raw data generated by a computer-aided design (CAD) program. Such raw data includes: topography, roads centerlines plan, road cross-sections and earthwork unit prices. It is to be noted that the invention is also applicable to railway transport systems, and within the context of the following description and claims, a "transport system" is any highway system comprising one or more roads, pedestrian routes or rail tracks or a combination thereof. The invention is of particular benefit for the optimization of complete transport systems having many intersecting roads or rail tracks, whilst nevertheless being applicable to the design of single transport routes only.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 is a flow diagram showing the principal operating steps associated with a method of road design according to the invention;

Fig. 2 shows schematically a relation between grid and control points for grid optimization;

Fig. 3 shows pictorially a "Fill – Cut" geometrical presentation for a centerline linear model objective function;

Fig. 4 shows pictorially a relative proposed unsigned elevations for centerline nonlinear model objective function; and

Fig. 5 is a block diagram showing functionally a system for optimizing cut and fill costs for a transportation route in accordance with the invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Fig. 1 is a flow diagram showing the principal steps associated with an optimization process according to the invention using linear or nonlinear programming. Three approaches are described differing in the number of variables and the performance time.

1. Grid optimization approach:

The optimization is reached through nonlinear programming when the objective is to minimize the total cost of the earthworks. The required variables are differences between proposed road elevations and existing topography elevations at all grid points on the right of way. The relevant constraints are prevailing roads standards.

Fig. 2 shows in plan view a road surface 10 having superimposed thereon an imaginary matrix of grid points designated GP each being a node point of a rectangular grid of definite size (e.g. 5m x 5m) that are located on the right of way. Boundary grid points designated BGP are grid points located on edges of roads, i.e. points for which distance to the road centerline is equal to half of the road width (with some tolerance). Boundary grid points are used for cost estimation of retaining walls which support the earth under the road surface when the surface of the road is higher than that of the surrounding landscape, thus requiring earth to be filled to the level of the road surface. Likewise, retaining walls are built when the level of the surrounding landscape is higher than that of the road surface, thus requiring the earth to be cut down to the level of the road surface. In this case, the retaining walls serve the function of preventing rubble from falling on to the road surface. Both grid points and boundary grid points are quantified by coordinates in 3-dimensional space.

Also shown are control points designated CP being 3D points on the proposed centerlines of the road system (e.g. every 100m). As shown in Fig. 2, control points are not necessarily coincident with grid points. The gradient

or “grade” of a road can be changed only at control points, such that each road section spanning a pair of control points is linear.

Referring back to Fig. 1, respective X and Y coordinates of control points and grid points are entered as input data and coordinates Z are an output of the optimization procedure. Preferably, control points are located at points of centerlines where grades of the existing profile are changed, in order to improve the optimization process. Optimization of control points and grid points is formulated as a nonlinear programming task, as follows:

Let $GP = Q(X'_q, Y'_q, Z'_q)$

where Q is some arbitrary point on the road surface.

Therefore Q lies on some specific road within the designated road system. There then exist A(Xa,Ya,Za) and B(Xb,Yb,Zb) - adjacent control points on the specific road centerline so that Q is located between A and B. This implies that if Q′ is the nearest point to point Q on the specific road’s centerline including A and B, then Q′ is located between A and B. Since Q′ is the point nearest to Q, it follows that Q′ lies on a line perpendicular to the road centerline along which all points are horizontal. Thus, points Q and Q' must have identical elevations. Therefore for any point Q there exists $\lambda, \mu \in [0,1]$ so that:

$$Z'q = \lambda * Za + \mu * Zb,$$

Where:

Z'q, Za, Zb are proposed elevations of points Q, A, B respectively.

Seeing that by definition the interval AB is linear then it can be shown that:

$$\lambda = (\mathbf{AQ},\mathbf{AB})/(\mathbf{AB},\mathbf{AB}) \in [0,1], \text{ and}$$

$$\mu = 1 - \lambda.$$

where **AQ** and **AB** are vectors and μ and λ are simply constants of proportionality each being equal to the respective fractional displacement of the point Q from the points A and B.

This implies that the proposed elevation of each grid point may be determined by linear interpolation from the proposed elevations of a corresponding pair of control points.

Let $Z_q = Z'_q - Z_e$, where Z'_q is the proposed elevation and Z_e is the existing elevation at point Q.

The object is to minimize the total cost of the earthworks represented by the following objective function:

$$\sum_{q=1}^{q=N}(F_q(Z_q)\cdot G+W_q(Z_q)+C_q(Z_q)\cdot G+V_q(Z_q))\cdot G+D$$

Equation (1)

where:

G	is grid size (e.g. 5m);
$F_q(Z_q)$	is cost of fill at point Q, where the proposed GP elevation is higher than the existing GP elevation ($Z_q>0$);
$W_q(Z_q)$	is cost of retaining wall for fill at point Q, where proposal GP is above existing GP ($Zq>0$);
$C_q(Z_q)$	is cost of excavation at point Q, where the proposed GP is lower than the existing GP ($Z_q<0$);
$V_q(Z_q)$	is cost of retaining wall for excavation at point Q, where proposed GP is below existing GP ($Z_q<0$);
D	is cost of total difference between fill and excavation volumes moving in or out of entire roads system area.

If $Z_q < 0$ then $W_q(Z_q) = F_q(Z_q) = 0$; also if Q is not a boundary point then $W_q(Z_q)=0$ since retaining walls are, by definition, built at the road boundary.

If $Z_q > 0$ then $C_q(Z_q) = V_q(Z_q) = 0$. Here also, if Q is not a boundary point then $V_q(Z_q)=0$.

Let price of fill = f0 (money unit / volume unit), then

$F_q(Z_q)= 0.5*f0*(|Z_q| + Z_q)$;

Hence, if $Z_q < 0$ then $F_q(Z_q) = 0$.

If excavation price is constant=c0, then

$C_q(Z_q) = 0.5*c0*(| Z_q | - Z_q)$.

Hence, if $Z_q > 0$ then $C_q(Z_q) = 0$.

If excavation price depends on Z_q (e.g. due to different geology layers), prices may be entered as a table:

For $0 > aj_q > Z_q > bj_q$ the corresponding price is Pj_q and then:

$$C_q(Z_q) = 0.5 \cdot \left(\sum_{j=1}^{j=Kq} \left(|Z_q - aj_q| + aj_q - |Z_q - bj_q| - bj_q \right) \cdot Pj_q + \left\{ |Z_q - bK_q| - (Z_q - bK_q) \right\} \cdot P_q \max \right)$$

Equation (2)

If $Z_q > 0$, then $C_q(Z_q) = 0$.

K_q is number of different geological layers each having a specified excavation price at the point Q,

aj_q, bj_q – upper and lower depths of j^{th} layer at point Q,

Pj_q – excavation price of j^{th} layer at point Q (order of layers may be dependent on Q).

$P_q\max$ is excavation price for $Z_q < bK_q$. (Here Z_q, aj_q, bj_q, $bK_q < 0$).

If Q is BGP, then:

$$V_q(Z_q) = 0.5 \cdot \left(\sum_{j=1}^{j=M} \left(|Z_q - e_j| + e_j - |Z_q - f_j| - f_j \right) \cdot F_j + \left\{ |Z_q - fM| - (Z_q - fM) \right\} \cdot F \max \right)$$

Equation (3)

where:

for $0 > e_j > Z_q > f_j$ corresponding price of retaining wall for excavation is Fj denoting different unit costs of a retaining wall for different soil composition and (e_j, f_j) is an interval having a discrete price for excavating the retaining wall.

M is number of levels of wall for excavation prices.

Fmax is excavation wall price for $Z_q < fM < 0$.

If $Z_q > 0$, then $V_q(Z_q) = 0$.

$$W_q(Z_q) = 0.5 \cdot \left(\sum_{j=1}^{j=L} \left(|Z_q - c_j| - c_j - |Z_q + d_j| + d_j \right) \cdot W_j + \left\{ |Z_q - d_L| + (Z_q - d_L) \right\} \cdot V\max \right)$$

Equation (4)

where:

for $0 < c_j < Z_q < d_j$ corresponding price of retaining wall for fill is W_j:

L is number of levels of fill wall prices.

Wmax is wall price for $Zq > dL$.

If $Z_q < 0$, then $W_q(Z_q) = 0$.

Finally:

$$D = 0.5 \cdot G \cdot G \cdot \left\{ I \cdot \left(\sum_{q=1}^{q=N} Z_q + \left| \sum_{q=1}^{q=N} Z_q \right| \right) + O \cdot \left(\left| \sum_{q=1}^{q=N} Z_q \right| - \sum_{q=1}^{q=N} Z_q \right) \right\}$$

Equation (5)

where:

I is the price of conveying fill deficiency from another site to roads system area;

O is the price of removing of redundant fill outside of the roads system area;

N is total number of grid points on roads system.

Constraints include five sets:

a) Constraints of road surface

$Z_q = \lambda_q * Z'_q + \mu_q * Z''_q - Zq_e + \lambda_q * Z'_e + \mu_q * Z''_e$,

Where:

q $=1,\ldots,N$;

Z'_q, Z''_q are the relative elevations of the adjacent control points A and B having point Q located between them;

$Z_q e$ is existing elevation at point Q.

Z'_e, Z''_e are existing elevations at adjacent control points.

λ_q , μ_q are coefficients of linear interpolation of proposal elevation at point Q.

The above constraint expresses the requirement that the point Q is realized as the linear interpolation between the control points A and B, thus ensuring uniformity along the path described between points A and B.

Normally there are more than two grid points on each interval between control points. Therefore Z'_q and Z''_q can be linearly expressed via each pair Z_q1 and Z_q2 (except for the case where $\lambda_q1=\lambda_q2$ wherein the other pair must be used). This allows elimination of Z'_q and Z''_q from surface constraints, but imposes the following additional constraints:

b) Control points relation constraints:

The above-mentioned linear expressions for Z'_q and Z''_q via pairs of Z_q must be equal to such linear expressions for both adjacent intervals of control points respectively.

c) Constraints of allowable grades (separately for control points near to intersection (e.g. 50m) and for other control points).

$| H' + Z' - (H + Z) | / D < S,$

for all pairs of adjacent control points;

where:

H′, H are existing elevations of pair of adjacent control points ,

Z′ , Z are relative elevations of these control points; instead Z′ and Z implicit their linear expressions via corresponding Zq of grid points;

D is distance along the road between these control points;

S is maximal allowable grade for road, or for intersection (e.g. S = 10% or 6%).

d) Constraints of intersections: (elevations of intersection points of different roads must be same).

H + Z - (H′+ Z′) = 0, for all control points at intersections, where H, H′ are the existing elevations at the intersection. That is, at the intersection of two roads, the elevation of each road surface must be identical.

e) Constraints for lack or excess total fill or excavation volumes:

$$\sum_{q=1}^{q=N} Z_q > 0 \text{ or } \sum_{q=1}^{q=N} Z_q < 0$$

The expressions which appear in the objective function shown in Equation (1) include absolute values of the respective differences between variables and parameters, thus rendering the objective function non-linear. However, these absolute values can be transformed into linear form:

In case of:

$$\sum_{q=1}^{q=N} Z_q > 0$$

Equation (6)

i.e. fill > cut, Equation (1) is reduced as follows:

$$\sum_{q=1}^{q=N}\left(F_q(Z_q)\cdot G + W_q(Z_q) + C_q(Z_q)\cdot G + V_q(Z_q)\right) + \left(2\cdot G\cdot I\cdot \sum_{j=1}^{j=N} Z_j\right)$$

It has been noted that the expressions appearing in the objective function contain absolute values, thus rendering the objective function non-linear. This is necessary in order to reflect the fact that regardless of whether material is cut or filled at a particular point, the cost is always positive. On the other hand, because taking absolute values introduces non-linearities, the expression is not amenable to solution using linear programming. In order to allow for the inclusion of absolute expressions

whilst also allowing solution by means of linear programming, each of the expressions

$Z_q - a_i$, $Z_q - b_i$, $Z_q - c_j$, $Z_q - d_j$, $Z_q - e_j$, $Z_q - f_j$ is replaced by a pair of new variables, as follows:

(*) Z_q - ai = Uqai$_1$ – Uqai$_2$, i=1,…,Kq,

(*) Z_q - bi = Uqbi$_1$ – Uqbi$_2$, i=1,…,Kq,

(*) Z_q - bKq = UqbK$_1$ – UqbK$_2$;

(*) Z_q - c_j = Uqcj$_1$ – Uqcj$_2$, j=1,…,L,

(*) Z_q - d_j = Uqdj$_1$ – Uqdj$_2$, j=1,…,L,

(*) Z_q - d_L = UqdL$_1$ – UqdL$_2$;

(*) Z_q - e_j = Uqej$_1$ – Uqej$_2$, j=1,…,M,

(*) Z_q - f_j = Uqfj$_1$ – Uqfj$_2$, j=1,…,M,

(*) Z_q - f_M = UqfM$_1$ – UqfM$_2$.

In Equation (1) instead of | $Z_q - a_i$ | substitute Uqai$_1$ + Uqai$_2$ etc., so as to generate a Linear Programming task because all constraints are linear. The constraints no longer include Z_q, but only their expressions via Uq…$_1$,Uq…$_2$.

For example, the nonlinear form of $C_q(Z_q)$ shown in Equation (2):

$$C_q(Z_q) = 0.5 \cdot \left(\sum_{j=1}^{j=Kq} \left(\left|Z_q - aj_q\right| + aj_q - \left|Z_q - bj_q\right| - bj_q \right) \cdot Pj_q + \left\{ \left|Z_q - bK_q\right| - \left(Z_q - bK_q\right) \right\} \cdot P_q \max \right)$$

and repeated above will be replaced by linear form:

$$C_q(Z_q) = 0.5 \cdot \left(\sum_{j=1}^{j=Kq} (Uqaj1 + Uqaj2 - Uqbj1 - Uqbj2) \cdot P_j + (2 \cdot UqbK2) \cdot Pq \max \right)$$

Equation (7)

where:

all aj, bj, Pj, bK_q, $P_q$max are constants and their sums and products have no influence on the optimization.

It can be shown that, after optimization, one of the substituted pair of variables in the above set of linearized equations marked (*),will be equal to zero whilst the second substituted variable in the corresponding pair will be greater than or equal to zero, i.e. U…1=0 and U…2≥0, or U…2=0 and U…1≥0.

The cost can be further reduced by increasing the number of control points and/or by allowing the road surface to have a higher gradient.

The accuracy of the result can be improved by reducing the spacing between adjacent grid points and employing a finer resolution Digital Terrain Model, but this dramatically increases the number of variables.

2. Centerline optimization - Linear programming approach.

The method described above allows cost optimization of the complete surface of a transport route typically comprising many roads or railway track surfaces. There may, however, be times when optimization of the complete surface is impractical or undesirable, for example when time or memory considerations do not allow such optimization. In this case, a lower precision approximation may be achieved by optimizing only the routes' centerlines using linear programming when the objective is to minimize the cumulative difference between the proposed roads' elevations and the existing elevations dictated by the initial topography at the control points, i.e. the difference between cut and fill volumes for centerlines only at each control point.

This approach takes into account only the control points i.e. points on the centerlines of the road system.

The gradient of a road can be changed only at the control points which are defined by the end-user, either manually or automatically. Preferably, the control points are located at the points of centerlines where the gradient of the existing profile changes, thereby improving the optimization process. Fig. 3 shows existing and proposed vertical profiles of road centerline.

Suppose SABO is the area of $\triangle ABO$, and SODC is the area of $\triangle ODC$. Then it can be shown that:

SABO – SODC = AA′ (BA + CD) / 2;

Where:

AA′ is planar distance between A and D (later D_{ij});

AB, DC are signed relative proposal elevations at control points A and D (later Z_{ij});

SABO is fill quantity;

SODC is cut quantity;

Summing the cut and fill differences for all control points so as to give the cumulative difference for a single road and then summing again for all roads in the system, gives:

$$\sum_{j=1}^{j=K} \sum_{i=1}^{i=N_j} \left(D_{(i-1)j} + D_{ij}\right) \cdot Z_{ij}$$

Equation (8)

where:

K is number of roads in the road system;

N_j is number of control points on the j^{th} road of the system;

Dij is the planar distance between adjacent control points with relative elevations Z_{ij} and $Z_{(i+1)j}$ on the j^{th} road;

$D_{0j} = D_{Njj} = 0$ by definition;

$j = 1,\ldots,K$,

$i = 1,\ldots,N_j$,

In the above Equation (8), Z_{ij} can be either positive or negative depending on whether the road surface must be cut or filled at the specific control point described by Z_{ij}. In order to construct a set of equations which can be solved using linear programming techniques, Z_{ij} must be positive for

all points. Values of Z_{ij} have units of meters and a value of 10,000 is added to each value of Z_{ij} so that, regardless of its value, there will thus emerge a positive value. To satisfy implicit constraints for all variables: ≥ 0 instead of relative elevations we used $Z_{ij}+10{,}000$. This has no effect on constraints based only on compensate for the hidden addition of 10,000. It should be noted that the value 10,000 is itself arbitrary and any other value, Δ, may be employed so long as it is sufficiently large that for all values of Z_{ij}, the sum of $Z_{ij} + \Delta$ is always ensured to be greater than zero.

In order to compensate for the addition of 10,000 to each value of Z_{ij}, there must now be subtracted 10,000 from the cumulative sum in respect of each Z_{ij}:

$$-\sum_{j=1}^{j=K}\sum_{i=1}^{i=N_j}\left(D_{(i-1)j}+D_{ij}\right)\cdot 10{,}000 \qquad \text{Equation (9)}$$

This gives:

$$\sum_{j=1}^{j=K}\sum_{i=1}^{i=N_j}\left(D_{(i-1),j}+D_{ij}\right)\cdot\left(Z_{ij}+10{,}000\right)-\sum_{j=1}^{j=K}\sum_{i=1}^{i=N_j}\left(D_{(i-1),j}+D_{ij}\right)\cdot 10{,}000$$

Equation (10)

Equation (10) is the objective function whose absolute value must be minimized in order to minimize the cumulative difference between cut and fill elevations. Two cases must be considered: (i) when the result of Equation (10) is positive and (ii) when the result of Equation (10) is negative. When the cumulative difference between cut and fill elevations given by Equation (10) is negative, the cumulative difference must be maximized, whilst when it is positive, it must be minimized. so that in either case the absolute cumulative difference is minimized. A further constraint is introduced in order to indicate which of the two cases is applicable. This gives:

$$\sum_{j=1}^{j=K}\sum_{i=1}^{i=N_j}\left(D_{(i-1),j}+D_{ij}\right)\cdot\left(Z_{ij}+10{,}000\right)-\sum_{j=1}^{j=K}\sum_{i=1}^{i=N_j}\left(D_{(i-1),j}+D_{ij}\right)\cdot 10{,}000<0 \text{ or } >0$$

Equation (11)

Constraints:

(a) Elevations of intersection points of different roads having respective indices j1 and j2 must be same, i.e.:

$Z1_{j1}+H1_{j1}-Z1_{j2}-H1_{j2}=0$,

Where:

1st point of j1th road coincides with 1st point of j2th road;

$Z1_{j1}$ and $Z1_{j2}$ are relative elevations at these points;

$H1_{j1}$ and $H1_{j2}$ are existing elevations at these points.

(b) The absolute value of the gradient between adjacent control points (i, j) having respective elevations H_{ij} and $H_{(i+1),j}$ cannot exceed a predetermined allowable maximum value, Gmax:

$| Z_{i,j}+H_{i,j}-Z_{(i+1),j}-H_{(i+1),j} | / D_{i,j} < G\max$,

for $j = 1,\ldots, K$; $i = 1,\ldots,N_j$.

(c) Elevation at each CP should belong to maximal possible allowable interval:

$$Z_{i_0,j_0}<10{,}000+\max\left\{0,0.5\cdot\left\{\max_{i=1}^{i=K}\max_{j=1}^{j=N_j}\left(H_{i,j}-H_{i_0,j_0}-D_{i_0,j_0,i,j}\cdot G\max\right)\right\}\right\}$$

Equation (12)

and

$$Z_{i_0,j_0}>10{,}000-\min\left\{0,0.5\cdot\left\{\min_{i=1}^{i=K}\min_{j=1}^{j=N_j}\left(H_{i,j}-H_{i_0,j_0}+D_{i_0,j_0,i,j}\cdot G\max\right)\right\}\right\}$$

Equation (13)

for $j_0 = 1,\ldots,K$; $i_0 = 1,\ldots,N_j$

Where:

$Z_{i0,j0}$-10,000 is the proposed relative elevation at the i_0^{th} point on j_0^{th} road;

$D_{i0,j0}i,j$ is the shortest distance between i_0^{th} point on j_0^{th} road to i^{th} point on j^{th} road.

This distance is the weighted graph shortest distance where weights of graph arcs are distances according to road paths, i.e. the shortest distance along the route rather than the shortest distance between two points. For this purpose the Shortest Paths Algorithm is used.

Centerline optimization - nonlinear programming approach.

Fig. 4 shows the proposed profile of a road to be constructed relative to an existing profile. The optimization is reached through nonlinear programming when objective is cumulative sum of unsigned differences between proposed and existing elevations.; variables are differences between proposal road elevations and existing topography elevations at all control points; constraints are present roads standards.

This approach also takes into account only control points i.e. points on centerlines of all roads in the system. It is recommended to locate control points at points of centerlines where the existing profile changes grade, so as thereby to improve the optimization process.

The objective is to minimize the total sum of unsigned differences between proposed and existing elevations calculated for the centerlines only of each road, i.e. for vertical profiles as shown in Fig. 4:

A, B, C, D, E are control points;

AA′ is the difference between the proposed elevation and the existing elevation at point A (later Z_{ij}).

$$\sum_{j=1}^{j=K} \sum_{i=1}^{i=N_j} |Z_{ij}| \Rightarrow \text{minimum}$$

Equation (14)

where:

K is number of roads; Nj is number of control points on j^{th} road of the system;

Dij is distance between adjacent control points with relative elevations Zij and $Z_{(i+j),j}$ on j^{th} road;

D0j = DNjj = 0 by definition;

j = 1,…,K,

i = 1,…,Nj.

Constraints:

(a) Elevations of intersection points of different roads must be same:

$Z_{1j1} + H_{1j1} - Z_{1j2} - H_{1j2} = 0$,

Where:

1^{st} point of j_1^{th} road coincides with 1^{st} point of $j2^{th}$ road;

Z1j1 and Z_{1j2} are proposed elevations at these points;

H1j1 and H_{1j2} are existing elevations at these points.

(b) Maximal grades at all control points cannot exceed allowable values:

$| Z_{ij} + H_{ij} - Z_{(i+1),j} - H_{(i+1),j} | / D_{ij} < Gmax$,

for j = 1,…,K; i =1,…,N_j.

To transform Equation (14) to linear form of variables substitute for each pair of variables as explained above.

Zij = Uij1 – Uij2 ,

Uij1,Uij2>=0,

for j = 1,…,K; i=1,…,N_j.

So in Equation (1) replace | Zij | by Uij1 + Uij2.

Replace all constraints by Zij = Uij1 – Uij2 for each corresponding index i, j.

Refinements:

If the control points are located close each to other (e.g. 10-50m) it is recommended to add as a further constraint that the difference between adjacent road grades should not exceed predefined value per certain distance (e.g. 0.5% per 10m). The received optimal centerlines may then be approximated by arcs of circles or parabolas or straight lines to satisfy roadway design rules.

If control points are located far each to other (e.g. 50-300m) arcs of circles or parabolas may be inscribed between straight intervals according to roadway design rules.

After the solution has been obtained, there is started an iteration process of moving entire model along axis Z to minimize total cost whilst taking into account the roads' cross-sections. The result of the optimization is a set of control points elevations that define vertical alignment of the entire road system.

The result can be improved by adding control points and by allowing higher gradient.

Accuracy of the result can be improved by adding density of grid and DTM.

Fixed points:

By "fixed points" are meant centerline points that must be at a definite height. For such points there are added fixed points constraints:

$$H + Z = E \qquad \text{Equation (15}$$

where:

Z is relative elevation of the fixed point;

H	is existing elevation at this point;
E	is required height at the fixed point.

Equation (15) is solved for each fixed point. This requires that each fixed point must be defined as a control point. If there are two or more fixed points, in each optimization method, it is necessary to ensure, before optimization, that grades between the fixed points do not exceed the maximal allowable value. This checking must be done for the shortest distance between fixed points. For that purpose the Shortest Paths Algorithm is used.

Subdivision:

If the optimization process takes into account earthworks required to conform the road elevation to the corresponding elevations of subdivision lots, such as private land adjoining the road boundary, then it is necessary add to the model the proposed sections and boundaries of lots.

Optimization Algorithm for Fill Transportation:

The invention allows determination of the optimal work program for transportation of excavation material at the preliminary planning stage. According to the invention, the suppliers are sites with excess of cut and the customers are sites with lack of fill. The objective is to minimize the sum of excavation volumes multiplied by distances, as given by:

$$\sum_{i=1}^{i=N} \sum_{j=1}^{j=M} D_{ij} \cdot X_{ij} \Rightarrow \text{minimum}$$

Equation (16)

where:

X_{ij}	is fill quantity will be moved from i^{th} supplier to j^{th} customer; $i=1,\ldots,N$, $j=1,\ldots,M$;
N	is number of suppliers and M is number of customer;
D_{ij}	is the shortest distance from i^{th} supplier to j^{th} customer;

Constraints are:

(a) Move no more than each customer needs:

$$\sum_{i=1}^{i=N} X_{ij} < P_j; j = 1;\ldots, M \qquad \text{Equation (17)}$$

P_j is volume of j^{th} customer;

(b) Move no more than each supplier has available:

$$\sum_{j=1}^{j=M} X_{ij} < Q_i; i = 1;\ldots, N \qquad \text{Equation (18)}$$

Q_i is volume of i^{th} supplier;

(c) But move all that is possible:

$$\sum_{i=1}^{i=N} \sum_{j=1}^{j=M} X_{ij} = \min\left(\sum_{j=1}^{j=M} P_j, \sum_{i=1}^{i=N} Q_i\right) \qquad \text{Equation (19)}$$

The shortest distance between two points is calculated by the shortest path algorithm as applied to weighted graphs whose arcs are the road paths and for which the weights are lengths of these paths.

It will be appreciated that the method described above is particularly amenable to being implemented by a suitably programmed computer. Fig. 5 shows functionally a computer-implemented system depicted generally as 10 for designing transportation routes, comprising a computer 11 coupled to a memory 12 and a data output device 13 such as a display monitor, plotter, printer and the like.

Stored in the memory 12 are transportation route data including:

design criteria to be met in respect of at least one of said transportation routes,

- route profile data showing land heights at sampled points along each of said at least one transportation route, and
- per-unit cost estimates in respect of land-cut and land-fill operations.

The computer 11 is so programmed as to be responsive to the design criteria, the route profile data and the per-unit cost estimates for computing a height profile of each transportation route which meets the design criteria and for which the land-cut and land-fill operations are adjusted to give a minimum cost in accordance with the method described in detail above with reference to Figs. 1 to 4 of the drawings.

It will also be understood that the invention contemplates use of a programmable computer such as a PC wherein the method is carried out by means of a custom program stored on diskette, CD-ROM or other suitable data media.

In the method claims which follow, alphabetic and numeric characters used to designate claim steps are provided for convenience only and do not imply any particular order of performing the steps.

CLAIMS:

1. A computer-implemented method for designing transportation routes, the method comprising the steps of:

(a) supplying linear constraints of allowable grades to be met in respect of at least one of said transportation routes,

(b) obtaining route profile 3-D coordinates showing land heights at sampled points along each of said at least one transportation route prior to construction thereof,

(c) supplying cost estimates per working unit in respect of land-cut and land-fill operations, and

(d) computing a height profile of said at least one transportation route which meets said constraints and for which said land-cut and land-fill operations are adjusted to give a minimum cost by replacing all non-linear constraints by equivalent linear constraints so as to render the height profile solving using standard linear programming tools.

2. The method according to Claim 1, wherein step **(d)** includes:

i) representing a surface of the at least one transportation route as a 3-dimensional model having grid points and boundary grid points being grid points located on edges of roads for which distance to the road centerline is substantially equal to half of the road width,

ii) defining control points such that a gradient of the road surface is constant between adjacent control points by entering X and Y coordinates of said control points as input data, and

iii) calculating a respective elevation of each point on the road surface between adjacent control points as well as a respective elevation of each control point using linear or non-linear programming.

3. The method according to Claim 1 or 2, wherein the route profile data includes soil composition and per unit excavation cost for each different level having a discrete soil composition.

4. The method according to any one of the preceding claims, wherein:

the height profile is computed to minimize a total cost of the earthworks represented by the following objective function:

$$\sum_{q=1}^{q=N}(F_q(Z_q)\cdot G+W_q(Z_q)+C_q(Z_q)\cdot G+V_q(Z_q))\cdot G+D$$

where:

G	is grid size;
$F_q(Z_q)$	is cost of fill at point Q, where the proposed GP elevation is higher than the existing GP elevation (Z_q>0);
$W_q(Z_q)$	is cost of retaining wall for fill at point Q, where proposal GP is above existing GP (Zq>0);
$C_q(Z_q)$	is cost of excavation at point Q, where the proposed GP is lower than the existing GP (Z_q<0);
$V_q(Z_q)$	is cost of retaining wall for excavation at point Q, where proposed GP is below existing GP (Z_q<0);
D	is cost of total difference between fill and excavation volumes moving in or out of entire roads system area.

$Z_q = Z'_q - Z_e$, where Z'_q is the proposed elevation and Z_e is the elevation at point Q,

the cost $C_q(Z_q)$ is represented as the solution of a non-linear equation represented by:

$$C_q(Z_q)=0.5\cdot\left(\sum_{j=1}^{j=Kq}\left(|Z_q-aj_q|+aj_q-|Z_q-bj_q|-bj_q\right)\cdot Pj_q+\left\{|Z_q-bK_q|-(Z_q-bK_q)\right\}\cdot P_q\max\right)$$

and

each of the absolute expressions $Z_q - a_i$, $Z_q - b_i$, $Z_q - c_j$, $Z_q - d_j$, $Z_q - e_j$, $Z_q - f_j$ is replaced by a pair of new variables, as follows:

(*) Z_q - ai = $Uqai_1 - Uqai_2$, i=1,...,Kq,

(*) Z_q - bi = $Uqbi_1 - Uqbi_2$, i=1,...,Kq,

(*) Z_q - bKq = $UqbK_1 - UqbK_2$;

(*) Z_q - c_j = $Uqcj_1 - Uqcj_2$, j=1,...,L,

(*) Z_q - d_j = $Uqdj_1 - Uqdj_2$, j=1,...,L,

(*) Z_q - d_L = $UqdL_1 - UqdL_2$;

(*) Z_q - e_j = $Uqej_1 - Uqej_2$, j=1,...,M,

(*) Z_q - f_j = $Uqfj_1 - Uqfj_2$, j=1,...,M,

(*) Z_q - f_M = $UqfM_1 - UqfM_2$.

so as to render all of the constraints linear and amenable to computation using Linear Programming techniques.

5. The method according to Claim 2 or 3, further including:

(e) iteratively shifting said model vertically in order to minimize total cost whilst taking into account the cross-section of each transportation route, so as to derive a set of control points having elevations that define vertical alignment of the transportation routes.

6. The method according to Claim 5, further including the step of adding control points and allowing a surface of the transportation route between adjacent control points to have a higher gradient.

7. The method according to Claim 5 or 6, wherein accuracy is improved by reducing a mutual separation between adjacent grid points.

8. The method according to any one of Claims 5 to 7, wherein accuracy is improved by providing a higher resolution digital terrain model.

9. The method according to any one of the Claims 2 to 8, wherein at least one of the transportation routes includes one or more subdivision lots adjoining a boundary of the transportation route and in step **(d)(i)** there are added to the model respective sections and boundaries of said subdivision lots

so as to take into account earthworks required to conform an elevation of the transportation route to corresponding elevations of the subdivision lots.

10. The method according to any one of the preceding claims, wherein the transportation routes include at least one road.

11. The method according to any one of the preceding claims, wherein the transportation routes include at least one rail track.

12. The method according to any one of the preceding claims, wherein the transportation routes include at least one pedestrian path.

13. The method according to any one of the preceding claims applied to a plurality of transportation routes comprising an integrated project so as optimize excavation costs for the project.

14. A computer-implemented system for designing transportation routes, said system comprising a computer coupled to a memory and a data output device,

(a) there being stored in the memory transportation route data including:

i) linear constraints of allowable grades to be met in respect of at least one of said transportation routes,

ii) route profile 3-D coordinates showing land heights at sampled points along each of said at least one transportation route prior to construction thereof, and

iii) cost estimates per working unit in respect of land-cut and land-fill operations; and

(b) the computer being responsive to the linear constraints, the route profile 3-D coordinates and the cost estimates per working unit for computing a height profile of said at least one transportation route which meets said design criteria and for which said land-cut and land-fill operations are adjusted to give a minimum cost by replacing all non-linear constraints by equivalent linear constraints

so as to render the height profile solving using standard linear programming tools.

15. The system according to Claim 14, wherein the computer is programmed to:

i) represent a surface of the at least one transportation route as a 3-dimensional model having grid points and boundary grid points being grid points located on edges of roads for which distance to the road centerline is substantially equal to half of the road width,

ii) define control points such that a gradient of the road surface is constant between adjacent control points by entering X and Y coordinates of said control points as input data, and

iii) calculate a respective elevation of each point on the road surface between adjacent control points as well as a respective elevation of each control point using linear or non-linear programming.

16. The system according to any one of Claims 15, wherein the route profile data includes soil composition and per unit excavation cost for each different level having a discrete soil composition.

17. The system according to any one of Claims 14 to 16, wherein wherein the computer is programmed to compute the height profile by minimizing a total cost of the earthworks represented by the following objective function:

$$\sum_{q=1}^{q=N}(F_q(Z_q)\cdot G+W_q(Z_q)+C_q(Z_q)\cdot G+V_q(Z_q))\cdot G+D$$

where:

G is grid size;

$F_q(Z_q)$ is cost of fill at point Q, where the proposed GP elevation is higher than the existing GP elevation (Z_q>0);

$W_q(Z_q)$ is cost of retaining wall for fill at point Q, where proposal GP is above existing GP (Zq>0);

$C_q(Z_q)$ is cost of excavation at point Q, where the proposed GP is lower than the existing GP ($Z_q<0$);

$V_q(Z_q)$ is cost of retaining wall for excavation at point Q, where proposed GP is below existing GP ($Z_q<0$);

D is cost of total difference between fill and excavation volumes moving in or out of entire roads system area.

$Z_q = Z'_q - Z_e$, where Z'_q is the proposed elevation and Z_e is the elevation at point Q,

the cost $C_q(Z_q)$ is represented as the solution of a non-linear equation represented by:

$$C_q(Z_q) = 0.5 \cdot \left(\sum_{j=1}^{j=Kq} \left(|Z_q - aj_q| + aj_q - |Z_q - bj_q| - bj_q \right) \cdot Pj_q + \left\{ |Z_q - bK_q| - (Z_q - bK_q) \right\} \cdot P_q \max \right)$$

and

each of the absolute expressions $Z_q - a_i$, $Z_q - b_i$, $Z_q - c_j$, $Z_q - d_j$, $Z_q - e_j$, $Z_q - f_j$ is replaced by a pair of new variables, as follows:

(*) Z_q - ai = Uqai$_1$ – Uqai$_2$, i=1,…,Kq,

(*) Z_q - bi = Uqbi$_1$ – Uqbi$_2$, i=1,…,Kq,

(*) Z_q - bKq = UqbK$_1$ – UqbK$_2$;

(*) Z_q - c_j = Uqcj$_1$ – Uqcj$_2$, j=1,…,L,

(*) Z_q - d_j = Uqdj$_1$ – Uqdj$_2$, j=1,…,L,

(*) Z_q - d_L = UqdL$_1$ – UqdL$_2$;

(*) Z_q - e_j = Uqej$_1$ – Uqej$_2$, j=1,…,M,

(*) Z_q - f_j = Uqfj$_1$ – Uqfj$_2$, j=1,…,M,

(*) Z_q - f_M = UqfM$_1$ – UqfM$_2$.

so as to render all of the constraints linear and amenable to computation using Linear Programming techniques.

18. The system according to Claim 15 to 17, further including:

(f) a vertical shifter for iteratively shifting said model vertically in order to minimize total cost whilst taking into account the cross-section of each transportation route, so as to derive a set of control

points having elevations that define vertical alignment of the transportation routes.

19. The system according to Claim 18, further including the step of adding control points and allowing a surface of the transportation route between adjacent control points to have a higher gradient.

20. The system according to Claim 18 or 19, wherein accuracy is improved by reducing a mutual separation between adjacent grid points.

21. The system according to any one of Claims 18 to 20, wherein accuracy is improved by providing a higher resolution digital terrain model.

22. The system according to any one of the Claims 15 to 21, wherein:

at least one of the transportation routes includes one or more subdivision lots adjoining a boundary of the transportation route,

there is further stored in the memory data relating to respective sections and boundaries of said subdivision lots, and

the computer is responsive to the respective sections and boundaries of the subdivision lots so as to take into account earthworks required to conform an elevation of the transportation route to corresponding elevations of the subdivision lots.

23. The system according to any one of Claims 14 to 22, wherein the transportation route data includes data relating to at least one road.

24. The system according to any one of the preceding claims, wherein the transportation route data includes data relating to at least one rail track.

25. The system according to any one of Claims 14 to 24, wherein the transportation route data includes data relating to at least one pedestrian path.

26. The system according to any one of Claims 14 to 25 for processing data relating a plurality of transportation routes comprising an integrated project so as optimize excavation costs for the project.

27. A storage medium storing therein a computer program for carrying out the method of any one of claims 1 to 13.

1/5

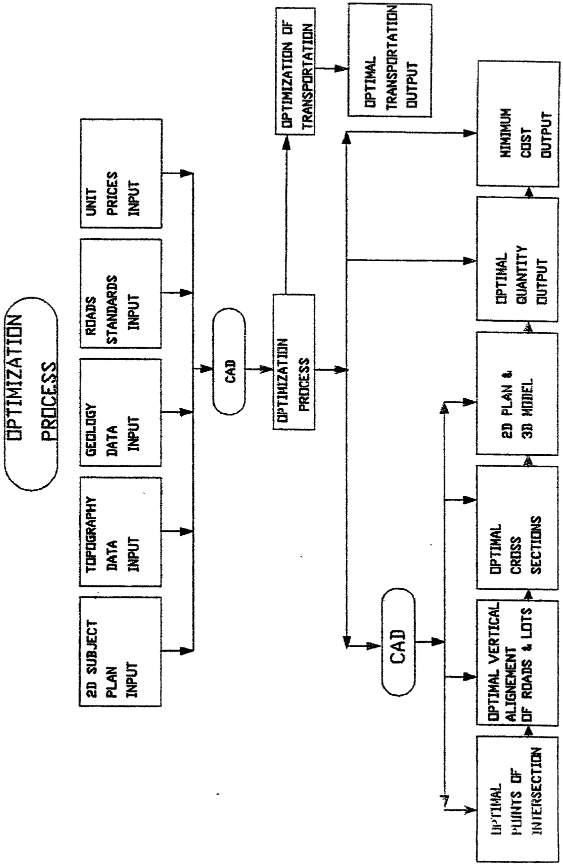

OPTIMIZATION PROCESS
2D SUBJECT PLAN INPUT
TOPOGRAPHY DATA INPUT
GEOLOGY DATA INPUT
ROADS STANDARDS INPUT
UNIT PRICES INPUT
CAD
OPTIMIZATION PROCESS
OPTIMIZATION OF TRANSPORTATION
OPTIMAL TRANSPORTATION OUTPUT
CAD
OPTIMAL POINTS OF INTERSECTION
OPTIMAL VERTICAL ALIGNEMENT OF ROADS & LOTS
OPTIMAL CROSS SECTIONS
2D PLAN & 3D MODEL
OPTIMAL QUANTITY OUTPUT
MINIMUM COST OUTPUT

FIG. 1

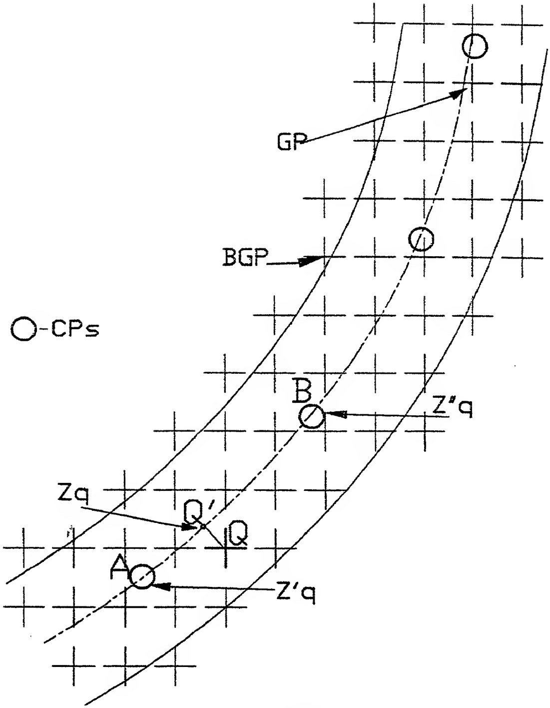


FIG. 2

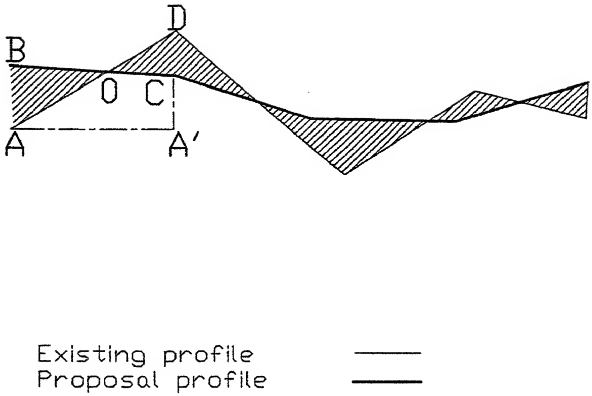
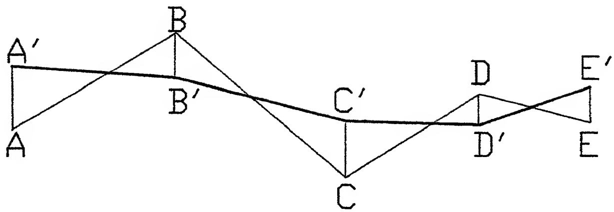


FIG. 3



Existing profile
Proposal profile

A, B, C, D, E are existing CPs elevations.

A′, B′, C′, D′, E′ are proposal CPs elevations.

FIG. 4

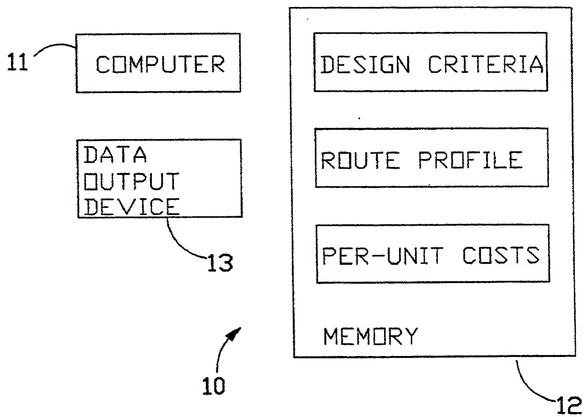

11
COMPUTER
DATA
OUTPUT
DEVICE
13
10
DESIGN CRITERIA
ROUTE PROFILE
PER-UNIT COSTS
MEMORY
12

FIG. 5

Practitioner's Docket No. U 013436-2 *PATENT*

Optional Customer No. Bar Code

00140

PATENT TRADEMARK OFFICE

COMBINED DECLARATION AND POWER OF ATTORNEY

(ORIGINAL, DESIGN, NATIONAL STAGE OF PCT, SUPPLEMENTAL, DIVISIONAL, CONTINUATION, OR C-I-P)

As a below named inventor, I hereby declare that:

TYPE OF DECLARATION

This declaration is of the following type:

(check one applicable item below)

[ ] original.
[ ] design.

NOTE: With the exception of a supplemental oath or declaration submitted in a reissue, a supplemental oath or declaration is not treated as an amendment under 37 CFR 1.312 (Amendments after allowance). M.P.E.P. Section 714 16, 7th Ed.

[ ] supplemental.

NOTE: If the declaration is for an International Application being filed as a divisional, continuation or continuation-in-part application, do not check next item; check appropriate one of last three items.

[x] national stage of PCT.

NOTE: If one of the following 3 items apply, then complete and also attach ADDED PAGES FOR DIVISIONAL, CONTINUATION OR C-I-P.

NOTE: See 37 C F.R Section 1.63(d) (continued prosecution application) for use of a prior nonprovisional application declaration in the continuation or divisional application being filed on behalf of the same or fewer of the inventors named in the prior application.

[ ] divisional.
[ ] continuation.

NOTE: Where an application discloses and claims subject matter not disclosed in the prior application, or a continuation or divisional application names an inventor not named in the prior application, a continuation-in-part application must be filed under 37 C.F.R. Section 1.53(b) (application filing requirements-nonprovisional application).

[ ] continuation-in-part (C-I-P).

INVENTORSHIP IDENTIFICATION

WARNING: *If the inventors are each not the inventors of all the claims, an explanation of the facts, including the ownership of all the claims at the time the last claimed invention was made, should be submitted.*

My residence, post office address and citizenship are as stated below, next to my name. I believe that I am the original, first and sole inventor *(if only one name is listed below)* or an original, first and joint inventor *(if plural names are listed below)* of the subject matter that is claimed, and for which a patent is sought on the invention entitled:

TITLE OF INVENTION

COMPUTER-IMPLEMENTED METHOD AND SYSTEM FOR DESIGNING ROUTES

SPECIFICATION IDENTIFICATION

The specification of which:

(complete (a), (b), or (c))

(a) [ ] is attached hereto.

NOTE: *"The following combinations of information supplied in an oath or declaration filed on the application filing date with a specification are acceptable as minimums for identifying a specification and compliance with any one of the items below will be accepted as complying with the identification requirement of 37 C.F.R. Section 1.63:*

"(1) name of inventor(s), and reference to an attached specification which is both attached to the oath or declaration at the time of execution and submitted with the oath or declaration on filing;

"(2) name of inventor(s), and attorney docket number which was on the specification as filed; or

"(3) name of inventor(s), and title which was on the specification as filed."

Notice of July 13, 1995 (1177 O.G. 60).

(b) [ ] was filed on ______________, [ ] as Application No. __________________
[ ] and was amended on ____________________ (if applicable).

NOTE: *Amendments filed after the original papers are deposited with the PTO that contain new matter are not accorded a filing date by being referred to in the declaration. Accordingly, the amendments involved are those filed with the application papers or, in the case of a supplemental declaration, are those amendments claiming matter not encompassed in the original statement of invention or claims. See 37 C.F.R. Section 1.67.*

NOTE: *"The following combinations of information supplied in an oath or declaration filed after the filing date are acceptable as minimums for identifying a specification and compliance with any one of the items below will be accepted as complying with the identification requirement of 37 C.F.R. Section 1.63:*

(A) application number (consisting of the series code and the serial number, e.g., 08/123,456);

(B) serial number and filing date;

(C) attorney docket number which was on the specification as filed;

(D) title which was on the specification as filed and reference to an attached specification which is both attached to the oath or declaration at the time of execution and submitted with the oath or declaration; or

(E) title which was on the specification as filed and accompanied by a cover letter accurately identifying the application for which it was intended by either the application number (consisting of the series code and the serial number, e.g., 08/123,456), or serial number and filing date. Absent any statement(s) to the contrary, it will be presumed that the application filed in the PTO is the application which the inventor(s) executed by signing the oath or declaration

M.P.E.P. Section 601.01(a), 7th ed.

(c) [x] was described and claimed in PCT International Application No. PCT/IL99/00538 filed on 13 October 1999 and as amended under PCT Article 19 on __________ *(if any).*

SUPPLEMENTAL DECLARATION (37 C.F.R. Section 1.67(b))

(complete the following where a supplemental declaration is being submitted)

[ ] I hereby declare that the subject matter of the

[ ] attached amendment
[ ] amendment filed on ______________.

was part of my/our invention and was invented before the filing date of the original application, above identified, for such invention.

ACKNOWLEDGMENT OF REVIEW OF PAPERS AND DUTY OF CANDOR

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information, which is material to patentability as defined in 37, Code of Federal Regulations, Section 1.56,

(also check the following items, if desired)

[ ] and which is material to the examination of this application, namely, information where there is a substantial likelihood that a reasonable Examiner would consider it important in deciding whether to allow the application to issue as a patent, and

[ ] in compliance with this duty, there is attached an information disclosure statement, in accordance with 37 C.F.R. Section 1.98.

PRIORITY CLAIM (35 U.S.C. Section 119(a)-(d))

NOTE: "The claim to priority need be in no special form and may be made by the attorney or agent if the foreign application is referred to in the oath or declaration as required by Section 1.63. The claim for priority and the certified copy of the foreign application specified in 35 U.S.C. Section 119(b) must be filed in the case of an interference (Section 1.630), when necessary to overcome the date of a reference relied upon by the examiner, when specifically required by the examiner, and in all other situations, before the patent is granted. If the claim for priority or the certified copy of the foreign application is filed after the date the issue fee is paid, it must be accompanied by a petition requesting entry and by the fee set forth in Section 1.17(i). If the certified copy is not in the English language, a translation need not be filed except in the case of interference; or when necessary to overcome the date of a reference relied upon by the examiner; or when specifically required by the examiner, in which event an English language translation must be filed together with a statement that the translation of the certified copy is accurate." 37 C.F.R. Section 1.55(a).

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d) of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed.

(complete (d) or (e))

(d) [ ] no such applications have been filed.

(e) [x] such applications have been filed as follows.

NOTE: Where item (c) is entered above and the International Application which designated the U.S. itself claimed priority check item (e), enter the details below and make the priority claim.

PRIOR FOREIGN/PCT APPLICATION(S) FILED WITHIN 12 MONTHS (6 MONTHS FOR DESIGN) PRIOR TO THIS APPLICATION AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. SECTION 119(a)-(d)

COUNTRY (OR INDICATE IF PCT)	APPLICATION NUMBER	DATE OF FILING DAY, **MONTH**, YEAR	PRIORITY CLAIMED UNDER 35 USC 119
IL	126962	9 November 1998	[x]YES [ ]NO
			[ ]YES [ ]NO
			[ ]YES [ ]NO
			[ ]YES [ ]NO
			[ ]YES [ ]NO

CLAIM FOR BENEFIT OF PRIOR U.S. PROVISIONAL APPLICATION(S)
(35 U.S.C. Section 119(e))

I hereby claim the benefit under Title 35, United States Code, Section 119(e) of any United States provisional application(s) listed below:

PROVISIONAL APPLICATION NUMBER	**FILING DATE**
______/______	______
______/______	______
______/______	______

CLAIM FOR BENEFIT OF EARLIER U.S./PCT APPLICATION(S) UNDER 35 U.S.C. SECTION 120

[ ] The claim for the benefit of any such applications are set forth in the attached ADDED PAGES TO COMBINED DECLARATION AND POWER OF ATTORNEY FOR DIVISIONAL, CONTINUATION OR CONTINUATION-IN-PART (C-I-P) APPLICATION.

ALL FOREIGN APPLICATION(S), *IF ANY,* FILED MORE THAN 12 MONTHS (6 MONTHS FOR DESIGN) PRIOR TO THIS U.S. APPLICATION

___

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NOTE: *If the application filed more than 12 months from the filing date of this application is a PCT filing forming the basis for this application entering the United States as (1) the national stage, or (2) a continuation, divisional, or continuation-in-part, then also complete ADDED PAGES TO COMBINED DECLARATION AND POWER OF ATTORNEY FOR DIVISIONAL, CONTINUATION OR C-I-P APPLICATION for benefit of the prior U.S. or PCT application(s) under 35 U.S.C. Section 120.*

POWER OF ATTORNEY

I hereby appoint the following practitioner(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

(list name and registration number)

JOSEPH H. HANDELMAN, 26179

JOHN RICHARDS, 31053

RICHARD J. STREIT, 25765

PETER D. GALLOWAY, 27885

IAIN C. BAILLIE, 24090

RICHARD P. BERG, 28145

JULIAN H. COHEN, 20302

WILLIAM R. EVANS 25858

JANET I. CORD, 33778

CLIFFORD J. MASS, 30086

CYNTHIA R. MILLER, 34678

(Check the following item, if applicable)

[ ] I hereby appoint the practitioner(s) associated with the Customer Number provided below to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

[ ] Attached, as part of this declaration and power of attorney, is the authorization of the above-named practitioner(s) to accept and follow instructions from my representative(s).

NOTE *"Special care should be taken in continuation or divisional applications to ensure that any change of correspondence address in a prior application is reflected in the continuation or divisional application. For example, where a copy of the oath or declaration from the prior application is submitted for a continuation or divisional application filed under 37 CFR 1.53(b) and the copy of the oath or declaration from the prior application designates an old correspondence address, the Office may not recognize, in the continuation or divisional application, the change of correspondence address made during the prosecution of the prior application Applicant is required to identify the change of correspondence address in the continuation or divisional application to ensure that communications from the Office are mailed to the current correspondence address. 37 CFR 1.63(d)(4)." Section 601.03, M.P.E P., 7th Ed*

SEND CORRESPONDENCE TO

Ladas & Parry
26 West 61st Street
New York, N.Y. 10023

DIRECT TELEPHONE CALLS TO:
(Name and telephone number)

William R. Evans
(212) 708-1930

(complete the following if applicable)

Since this filing is a [ ] continuation [ ] divisional there is attached hereto a Change of Correspondence Address so that there will be no question as to where the PTO should direct all correspondence.

DECLARATION

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

SIGNATURE(S)

NOTE. Carefully indicate the family (or last) name, as it should appear on the filing receipt and all other document.

NOTE: Each inventor must be identified by full name, including the family name, and at least one given name without abbreviation together with any other given name or initial, and by his/her residence, post office address and country of citizenship. 37 C.F.R. Section 1.63(a)(3).

NOTE: Inventors may execute separate declarations/oaths provided each declaration/oath sets forth all the inventors. Section 1.63(a)(3) requires that a declaration/oath, inter alia, identify each inventor and prohibits the execution of separate declarations/oaths which each sets forth only the name of the executing inventor. 62 Fed. Reg. 53,131, 53,142, October 10, 1997,

Full name of sole or first inventor

David | | MYR

(Given Name) ***(Middle Initial or Name)*** ***Family (Or Last Name)***

Inventor's signature (x) D.M.

Date (x) 4 July 2001 **Country of Citizenship** ISRAELI

Residence YEHUDA STREET 32, 93467 JERUSALEM, ISRAEL

Post Office Address same as above

Full name of second joint inventor, if any

(Given Name) ***(Middle Initial or Name)*** ***Family (Or Last Name)***

Inventor's signature

Date **Country of Citizenship**

Residence

Post Office Address

Full name of third joint inventor, if any

(Given Name) ***(Middle Initial or Name)*** ***Family (Or Last Name)***

Inventor's signature

Date **Country of Citizenship**

Residence

Post Office Address

(check proper box(es) for any of the following added page(s) that form a part of this declaration)

[ ] **Signature** for fourth and subsequent joint inventors. *Number of pages added* ________

* * *

[ ] **Signature** by administrator(trix), executor(trix) or legal representative for deceased or incapacitated inventor. *Number of pages added* _________

* * *

[ ] **Signature** for inventor who refuses to sign or cannot be reached by person authorized under 37 C.F.R. Section 1.47. *Number of pages added* ________

* * *

[ ] Added page for **signature** by one joint inventor on behalf of deceased inventor(s) where legal representative cannot be appointed in time. (37 C.F.R. Section 1.47)

* * *

[ ] Added pages to combined declaration and power of attorney for divisional, continuation, or continuation-in-part (C-I-P) application.

[ ] Number of pages added ____________________

* * *

[ ] Authorization of practitioner(s) to accept and follow instructions from representative.

(If no further pages form a part of this Declaration, then end this Declaration with this page and check the following item)

[x] This declaration ends with this page.

Practitioner's Docket No. U 013436-2 *PATENT*

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

[x] In re application of: David **MYR**
Application No.: 09/831,093 Group No.: - -
Filed: May 3, 2001 Examiner: - -
For: COMPUTER-IMPLEMENTED METHOD AND SYSTEM FOR DESIGNING TRANSPORTATION ROUTES

[ ] *Patent No.: Issue Date:

**NOTE:* *Insert name(s) of inventor(s) and title also for patent Where statement is with respect to a maintenance fee payment, also insert application number and filing date, and add Box M. Fee to address.*

STATEMENT CLAIMING SMALL ENTITY STATUS (37 CFR 1.9(c-f) and 1.27(b-d))

With respect to the invention described in
[ ] the specification filed herewith.
[x] application no. 09/831,093, filed May 3, 2001.
[ ] patent no. ____________ issued ________________.

I. IDENTIFICATION AND RIGHTS AS A SMALL ENTITY

I hereby state that I am

(complete either (a), (b), (c) or (d) below)

(a) Independent Inventor

[X] a below named independent inventor, and that I qualify as an independent inventor, as defined in 37 CFR 1.9(c), for purposes of paying reduced fees under Sections 41(a) and (b) of Title 35, United States Code, to the Patent and Trademark Office.

(b) Noninventor Supporting a Claim by Another

[ ] making this statement to support a claim by

____

for a small entity status for purposes of paying reduced fees under Sections 41(a) and (b) of Title 35, United States Code. I hereby state that I would qualify as an independent inventor as defined in 37 CFR 1.9(c) for purposes of paying reduced fees under Sections 41(a) and (b) of Title 35, United States Code, if I had made the above identified invention.

(c) Small Business Concern

[ ] the owner of the small business concern identified below:

check one → [X] an official of the small business concern empowered to act on behalf of the concern identified below:

Name of Concern MAKOR ISSUES & RIGHTS LTD.
Address of Concern YEHUDA STREET 32, 93467 JERUSALEM, ISRAEL
and
that the above identified small business concern qualifies as a small business concern, as defined in 13 CFR 121.3-18, and reproduced in 37 CFR 1.9(d), for purposes of paying reduced fees under Sections 41(a) and (b) of Title 35, United States Code, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

(d) Non-Profit Organization

[ ] an official empowered to act on behalf of the nonprofit organization identified below:

Name of Organization ____________
Address of Organization ____________

TYPE OF ORGANIZATION

[ ] University or Other Institution of Higher Education
[ ] Tax Exempt Under Internal Revenue Service Code (26 USC 501(a) and 501(c) (3))

[ ] Nonprofit Scientific or Educational Under Statute of State of the United States of America
(Name of State____________)
(Citation of Statute____________)

[ ] Would Qualify as Tax Exempt Under Internal Revenue Service Code (26 USC 501(a) and 501(c) (3)), if Located in the United States of America

[ ] Would Qualify as Nonprofit Scientific or Educational Under Statute of State of the United States of America, if Located in the United States of America
(Name of State____________)
(Citation of Statute____________)

and that the nonprofit organization identified above qualifies as a nonprofit organization, as defined in 37 CFR 1.9(e), for purposes of paying reduced fees under Sections 41(a) and (b) of Title 35, United States Code.

II. OWNERSHIP OF INVENTION BY DECLARANT

I hereby state that rights under contract or law remain with and/or have been conveyed to the above identified

[ ] person (item (a) or (b) above)	[x] concern (item (c) above)	[ ] organization (item (d) above)

EXCEPT, that if the rights held are not exclusive, each individual, concern or organization having rights to the invention is listed below* and no rights to the invention are held (1) by any person who could not be classified as an independent inventor under 37 CFR 1.9(c) if that person had made the invention, (2) any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or (3) a nonprofit organization under 37 CFR 1.9(e).

[x] no such person, concern, or organization
[ ] person, concerns or organizations listed below*

*NOTE *Separate statements are required from each named person, concern or organization having rights to the invention as to their status as small entities. (37 CFR 1.27)*

Full Name MAROR Issues & Rights Ltd.
Address 32 Yehuda, Jerusalem, Israel, 93467
[ ] INDIVIDUAL [X] SMALL BUSINESS CONCERN [ ] NONPROFIT ORGANIZATION

Full Name ______
Address ______
[ ] INDIVIDUAL [ ] SMALL BUSINESS CONCERN [ ] NONPROFIT ORGANIZATION

III. ACKNOWLEDGEMENT OF DUTY TO NOTIFY PTO OF STATUS CHANGE

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

IV. DECLARATION

(check the following item, if desired)

NOTE: *The following verification statement need not be made in accordance with the rules published on October 10, 1997, 62 Fed. Reg. 52131, effective December 1, 1997.*

NOTE: *"The presentation to the Office (whether by signing, filing, submitting, or later advocating) of any paper by a party, whether a practitioner or non-practitioner, constitutes a certification under § 10.18(b) of this chapter. Violations of § 10 18(b)(2) of this chapter by a party, whether a practitioner or non-practitioner, may result in the imposition of sanctions under § 10.18(c) of this chapter. Any practitioner violating § 10.18(b) may also be subject to disciplinary action. See §§ 10 18(d) and 10.23(c)(15)." 37 CFR 1.4(d)(2).*

[X] I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

V. SIGNATURES

(complete only (e) or (f) below)

(e)
NOTE: All inventors must sign the statement.

DAVID MYR
Name of Inventor

D.M
Signature of Inventor Date: 4 JULY 2001

Name of Inventor

Signature of Inventor Date:

Name of Inventor

Signature of Inventor Date:

(add lines for any additional inventors who must sign)

or

(f)
NOTE: The title of the person signing on behalf of a concern or nonprofit organization should be specified.

Name of Person Signing (x) DAVID MYR

Title of Person (x) GENERAL MANAGER
(if signing on behalf of a concern or non-profit organization)

Address of Person Signing YEHUDA STREET 32, 93467 JERUSALEM, ISRAEL

SIGNATURE (x) D.M DATE (x) 4 July 2001